SPECIFICATION

METHOD FOR GROWING SEMICONDUCTOR SINGLE CRYSTAL

Technical Field

The present invention relates to a method for growing a semiconductor single crystal composed of, for example, silicon, by the Czochralski method (also referred to as "CZ method" hereinafter).

Background Art

Currently, semiconductor single crystals such as those composed of silicon are produced by the CZ method in many cases. As shown in Fig. 3, an apparatus for producing a semiconductor single crystal used for this CZ method comprises a crucible 4 in which a raw material 12 is charged, a heater 2 surrounding the crucible 4, a heat insulating material 8 disposed around the heater, pulling means for bringing a seed crystal 14 into contact with a melt in the crucible and growing a single crystal, and a metal chamber 17 for accommodating the aforementioned members.

In a conventional growing process of a semiconductor single crystal by the CZ method, a single crystal 13 is grown by using the aforementioned apparatus for producing a

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semiconductor single crystal, in which process the raw material 12 is charged in the crucible 4 and heated by the heater 2 surrounding the crucible 4 to form a melt, and the seed crystal 14 is brought into contact with the melt and slowly pulled with rotation to grow the single crystal 13. The single crystal 13 is pulled so that it should have a portion having an increasing diameter 13a, a portion having a constant diameter (also referred to as "straight body") 13b, which can be used as a product, and a portion having a decreasing diameter 13c, and it is detached from the melt after the portion having a decreasing diameter 13c is formed.

In order to obtain a high yield in the production of a single crystal, it is necessary to form the portion having a constant diameter as long as possible in contrast to the lengths of the portion having an increasing diameter and the portion having a decreasing diameter, and it is necessary that the pulling is performed from the melt in an amount as large as possible. If the diameter of the crystal becomes larger, the proportions of the portion having an increasing diameter and the portion having a decreasing diameter become larger. Therefore, the aforementioned necessity becomes more important, and it becomes more necessary to use a larger

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amount of the raw material by using a crucible having a larger diameter.

Further, as another factor for obtaining a high yield, it is also important to pull a single crystal ingot until the remaining amount of the melt reaches the possible smallest amount. In this specification, a value representing a ratio of weight of a grown single crystal relative to weight of initial raw material before the crystal is pulled, which is expressed in terms of percentage, is called a single crystal formation ratio. If this term is used, it can be said that, in order to pull a crystal having a large diameter with a high yield, it is important to use a crucible having a large diameter and, at the same time, pull a single crystal ingot at a high single crystal formation ratio.

However, since the radiant heat quantity from the melt surface increases with use of a crucible having a larger diameter, heating from the lateral direction only by the heater surrounding the crucible tends to become insufficient in terms of heating quantity. In particular, in the period of pulling of the latter half of the straight body of single crystal ingot or after the single crystal ingot is detached, the heat receiving area from the lateral direction is decreased, because the melt

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becomes shallow, and therefore the heating
efficiency is decreased. As a result, a phenomenon
of solidification of the melt frequently occurs.
The term "solidification" used herein means a
phenomenon that the surface or a part of internal
portion of the melt or the whole melt is cooled and
becomes solid. The worst result due to the
solidification phenomenon is caused when a solid
portion formed in the melt is contacted with the
growing interface of the crystal. In such a case,
because the crystal grows with dislocations
thereafter, the pulling of the single crystal
becomes impossible. Further, when most of the melt
is solidified, a stress is applied to a crucible
due to the volume change of the melt (volume
expansion in the case of silicon) and cracks may be
generated in the crucible. Therefore, it may be
necessary to stop the pulling of the crystal
thereafter.

In order to avoid such solidification of the
melt, it is contemplated to increase the electric
power supplied to the heater surrounding the
crucible as shown in Fig. 4. However, if the
heating quantity supplied from the heater is
increased, the temperature gradient of the single
crystal under pulling becomes small, and thus the
growing rate of the single crystal must be lowered.

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Alternatively or moreover, the crystal is gradually cooled in the temperature region in which crystal defects are formed, and thus there is caused a problem that defective size becomes larger. The crystal defects formed in this case are cavities called voids or aggregations (clusters) of dislocations, which are formed as a result that vacancies or interstitial atoms incorporated at the growing interface of the crystal aggregate during the subsequent cooling.

Further, if the electric power supplied to the heater is unduly increased, the temperature of the crucible is excessively elevated. As a result, the crucible may be deformed, or the internal surface of the crucible contacting with the melt may be degenerated. If the crucible is significantly deformed, the crucible touches the single crystal and the members including the heater, and it becomes unavoidable to interrupt the pulling. Further, when the crucible surface that is in contact with the melt is degenerated, the degenerated portions may fall off into the melt and reach the growing interface of the crystal, so that dislocations may be generated in the single crystal.

While the problems to be caused during the pulling of crystal when the amount of the melt remained in the crucible becomes small have been

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explained above, the problems concerning the
solidification and degradation of crucible due to
excessive heating by heater are similarly observed
with respect to the melt remained in the crucible
after a single crystal is detached. That is, the
solidification of the melt remained in the crucible
poses a problem when multi-pulling is performed.
The term "multi-pulling" used herein means that,
after a grown single crystal ingot is detached from
a melt and taken out from an apparatus for
producing a single crystal, a raw material is
additionally introduced into the melt remained in a
crucible and melted and then a seed crystal is
brought into contact with the melt to pull another
single crystal ingot again.

In the multi-pulling, it is necessary to
prevent the melt from rapidly solidifying during
the period after a single crystal is detached and
before finishing the additional charge of the raw
material and melting of the whole raw material in
the crucible. In particular, when a raw material
is newly added to a small amount of the melt, heat
of the melt is taken by the introduced raw material
and the temperature of the melt may be rapidly
decreased. At that time, if the melt is rapidly
solidified and thus an abnormal stress is applied
to the crucible due to the volume change of the raw

material, cracks may be generated in the crucible.

As explained above, conventional techniques could not prevent the solidification of melt in a crucible without affecting crystal quality and operability when a crystal is pulled at a high single crystal formation ratio by using a crucible having a large diameter, or when a raw material is additionally introduced into a limited amount of melt in the multi-pulling, and therefore suitable means for solving the problems have been desired.

Disclosure of the Invention

The present invention was accomplished in view of the aforementioned problems, and its object is to provide a method for preventing solidification of melt raw material decreased to a limited amount without affecting crystal quality, durability of crucible or the like.

The inventor of the present invention assiduously studied about a method for growing a crystal that enables continuous crystal pulling in crystal pulling using a crucible having a large diameter without inviting solidification of melt even when the amount of the melt is decreased to a limited amount. As a result, they conceived to solve the aforementioned problems by using subsidiary heating of the crucible from below,

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which shows constant heat conduction efficiency
even though the amount of the melt is decreased,
and made various improvements. Thus, they finally
accomplished the present invention.

In order to achieve the aforementioned object,
the method for growing a semiconductor single
crystal of the present invention is a method for
growing a semiconductor single crystal according to
the Czochralski method utilizing an apparatus for
producing a semiconductor single crystal having a
crucible to be charged with a raw material, a
heater surrounding the crucible, pulling means for
bringing a seed crystal into contact with a melt
contained in the crucible and growing a single
crystal and a metal chamber for accommodating the
foregoing members, wherein the apparatus is
provided with subsidiary heating means below the
crucible and the single crystal is pulled with
subsidiarily heating the crucible by the subsidiary
heating means in addition to the heating by the
heater surrounding the crucible for a period after
a ratio of a weight of the growing crystal during
the pulling of the crystal relative to a weight of
raw material melt before the growing becomes 60% or
more.

As described above, if the crucible is
subsidiarily heated from below for a period after a

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ratio of a weight of the growing crystal relative
to a weight of initial raw material melt before the
growing becomes 60% or more, where solidification
of the remaining melt becomes likely to occur, it
becomes possible to efficiently supplement heat to
the crucible from below for a wide area, even if
heat is taken away from the melt surface by
radiation. In addition, the heat receiving area
does not substantially change depending on the
amount of the melt, unlike the radiant heat from
the heater surrounding the crucible, and therefore
the method has characteristic that constant heating
efficiency is always obtained irrespective of the
amount of the melt. Further, the heating of the
bottom surface of the crucible accelerates heat
transfer by natural convection and hence the whole
melt is efficiently heated. Therefore, there can
be obtained better temporal response of the melt
temperature with respect to the electric power
supplied to the subsidiary heater compared with the
lateral heating. This means that it can cope with
a case where a crystal is pulled at a particularly
high rate and hence decreasing rate of the melt
amount is high.

Further it becomes unnecessary to unduly
increase the electric power supplied to the heater
surrounding the crucible, and variation of

temperature distribution of the single crystal and deformation or degeneration of the crucible are prevented. As a result of the above, it becomes possible to pull a crystal up to a high single crystal formation ratio even by using a crucible having a large diameter.

In the method of the present invention, the heating by the aforementioned subsidiary heating means is preferably performed so that temperature gradient of the single crystal surface along the pulling axis direction should be constant irrespective of the weight ratio of the growing crystal relative to the weight of raw material melt before the growing, and further, electric power values of the heater surrounding the crucible and the subsidiary heating means and/or a ratio of the both power values are preferably obtained by calculation based on global heat transfer analysis, the obtained value(s) is/are used as a target value or values of control, and electric powers supplied to the heater surrounding the crucible and the subsidiary heating means are preferably controlled to be as near the target value or values as possible during the pulling of the single crystal.

If the control is performed so that the single crystal ingot should have constant thermal history for the pulling direction as described above, size

and distribution of crystal defects can be kept
constant with respect to the pulling direction
irrespective of the decrease of the amount of the
melt, and therefore a crystal having a constant
quality can be obtained with a high yield.
Furthermore, if the electric powers supplied to the
heaters are controlled according to a value or
values determined by calculation based on global
heat transfer analysis, it becomes unnecessary to
determine a combination of electric powers supplied
to the heaters by trial and error basis in order to
obtain constant crystal quality along the pulling
direction. Therefore, production techniques can be
developed with low cost. The term "calculation
based on global heat transfer analysis" used herein
means numerical simulation wherein heat transfer by
radiation and conduction between structural members
of the apparatus for producing a single crystal is
calculated and thereby temperature distribution in
the apparatus is obtained.

The method for growing a semiconductor single
crystal of the present invention is also a method
for growing a semiconductor single crystal in which
multi-pulling is performed according to the
Czochralski method utilizing an apparatus for
producing a semiconductor single crystal having a
crucible to be charged with a raw material, a

heater surrounding the crucible, pulling means for
bringing a seed crystal into contact with a melt
contained in the crucible and growing a single
crystal and a metal chamber for accommodating the
foregoing members, wherein the apparatus is
provided with subsidiary heating means below the
crucible, and after a grown single crystal is
detached from the melt and taken out from the
apparatus for producing a crystal, a raw material
is newly added to the raw material remained in the
crucible and melted, and when a seed crystal is
brought into contact with the melt to pull a single
crystal again, the crucible is heated by the heater
surrounding the crucible and the subsidiary heating
means so that the raw material melt should not be
solidified at least for a period from the point of
the detachment of the single crystal ingot to the
point of complete melting of the raw material in
the crucible including the raw material newly added
thereto.

If the melt in the crucible is heated from
below as described above, occurrence of
solidification can be prevented even for a small
amount of melt remained in the crucible. It is
considered that this effect can be obtained by the
fact that a wide and constant area for receiving
heat from the subsidiary heater can be secured

irrespective of the amount of the melt in the
heating for the bottom surface of the crucible as
described above, and heat transfer in the melt is
accelerated by natural convection caused by the
heating of the bottom surface. As a result, the
raw material can be introduced at a high
introduction rate.

Further, it becomes unnecessary to markedly
increase the electric power supplied to the heater
surrounding the crucible, and hence deformation and
decrease of durability of the crucible due to
excessive heating can be preliminarily prevented.

Furthermore, since the amount of the melt to
be remained in the crucible can be reduced compared
with a conventional method, a single crystal can be
obtained with a high yield.

It is a case where, for example, a single
crystal having a diameter of 12 inches (300 mm) or
more is grown by using a crucible having an inner
diameter of 28 inch (about 711 mm) or more that the
method for growing a semiconductor single crystal
of the present invention is particularly effective.
In the case of silicon single crystals, an
increasingly larger diameter has been used, and it
is expected that a single crystal having a diameter
of 16 inches (400 mm) or 20 inches (500 mm) or more
will be required. Corresponding to it, the inner

diameter of the crucible also becomes larger, and the crystal growth will be performed in a crucible having an inner diameter of 40 inches (about 1000 mm) or 60 inches (about 1500 mm) or more. It can be said that, in such a case, the need for the present invention becomes still higher.

As explained above, even when a crucible having a large diameter is used, the present invention enables stable growth of a single crystal without generating solidification of melt until the amount of the raw material melt remained in the crucible becomes small. Further, the melt can be stably maintained at the time of additional introduction of the raw material in the multi-pulling. As a result, it becomes possible to obtain a single crystal with a high yield. Furthermore, it also becomes possible to pull a single crystal having crystal quality stabilized along the growing direction.

Brief Explanation of the Drawings

Fig. 1 is an explanatory view showing an exemplary apparatus for pulling a crystal used for the present invention.

Fig. 2 is a diagram showing exemplary relationship between electric powers supplied to heaters and a single crystal formation ratio at the

time of crystal pulling according to the present
invention.

Fig. 3 is an explanatory view showing an
exemplary conventional apparatus for pulling a
crystal.

Fig. 4 is a diagram showing exemplary
relationship between electric power supplied to a
heater and a single crystal formation ratio at the
time of conventional crystal pulling.

Best Mode for Carrying out the Invention

Hereafter, embodiments of the present
invention will be explained. However, the present
invention is not limited to these.

Fig. 1 is an explanatory view showing an
exemplary apparatus for pulling a single crystal
used for the present invention. As shown in Fig. 1,
the apparatus for pulling a crystal for producing a
crystal by the Czochralski method (semiconductor
single crystal production apparatus) 1 comprises a
quartz crucible 4 to be charged with a raw material
12 and a graphite crucible 5 that supports the
crucible 4, and further comprises a heater 2
surrounding the crucibles. Outside the heater 2, a
heat insulating material 8 is disposed so as to
obtain insulation effectiveness. These members are
each accommodated in a metal chamber 17.

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As for the pulling of a single crystal 13, a seed crystal 14 is held by a seed holder 15 connected to a wire 16 of which end is connected to a crystal pulling mechanism (not shown), and the seed crystal 14 is brought into contact with a melt 12 and slowly pulled with rotation to grow a single crystal 13. At this time, the single crystal 13 is pulled so that a portion having an increasing diameter 13a, a portion having a constant diameter 13b, and a portion having a decreasing diameter 13c should be successively formed in this order.

Below the crucible, there is provided a subsidiary heater 9 based on resistance heating as subsidiary heating means for heating the crucible from below. Below the subsidiary heater 9, there is disposed a heat insulating material 11 to obtain insulation effectiveness. As for the configuration of the subsidiary heater 9, it may have a structure and size that enable heating of the crucible from below irrespective of the amount of the melt, and it may have a shape corresponding to the shape of the crucible, or a shape that have a portion much or less extending from the bottom side of the crucible to the lateral side of the crucible. As the subsidiary heating means, it is possible to use not only such a subsidiary heater based on resistance heating as described above, but also a

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heater based on high frequency heating, a lamp for radiation heating and so forth.

The heater 2 can be moved upwardly and downwardly by a lift mechanism (not shown) via heater supporting shafts 3 supporting the heater. Similarly, the subsidiary heater 9 can be moved upwardly and downwardly by a lift mechanism (not shown) via supporting shafts 10. A graphite crucible 5 is built in a crucible supporting disk 6 supporting the crucible, and the crucible supporting disk 6 is fixed at the top end of a crucible shaft 7. The crucible shaft 7 can be freely moved upwardly and downwardly and rotated by a driving mechanism (not shown).

These graphite crucible 5, heater 2 and subsidiary heater 9 are in a positional relationship that can be freely changed depending on, for example, the remaining amount of the raw material 12 in the crucible during the pulling of a single crystal and other conditions.

The subsidiary heater 9 may be connected to an electric power source (not shown) controlled independent of the heater 2, or connected so that they should be cooperatively controlled. Since the crystal quality is influenced by the temperature gradient of the single crystal, it is preferred that electric power values of the both heaters

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and/or a ratio of the both power values are
preliminarily obtained by calculation based on
global heat transfer analysis, the obtained
value(s) is/are used as a target value or values of
control, and electric powers supplied to the
heaters are controlled to be as near the target
value or values as possible, in order to maintain
at least the temperature gradient along the pulling
axis direction to be constant even if the single
crystal formation ratio is changed. More
specifically, it is preferred that, for example, in
the calculation based on global heat transfer
analysis, electric power is applied to the heater 2
so that the temperature gradient of the single
crystal should become constant, and electric power
to be applied to the subsidiary heater 9 is
determined so that the heat balance of the whole
system and the diameter of the single crystal can
be arbitrarily controlled. In actual crystal
pulling, priority can be given to the change of the
electric power applied to the heater 2 with time
series, and the electric power applied to the
subsidiary heater 9 can be controlled as a
controllable factor involved in the control of
diameter of single crystal.

Hereafter, pulling of a semiconductor single
crystal using the aforementioned single crystal

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pulling apparatus 1 and a case of multi pulling
utilizing another addition of raw material will be
explained.

When a single crystal is pulled by using the
single crystal pulling apparatus 1, if the
remaining amount of the raw material melt 12 is
decreased, the area receiving heat from the heater
2 is decreased. On the other hand, heat is always
taken away from the melt surface by heat radiation
at a degree proportional to its area, i.e., square
of the inner diameter of the crucible. Therefore,
it becomes difficult to maintain the temperature of
the melt only by the heater 2. This tendency
becomes more significant as the diameter of the
crucible becomes larger.

Therefore, subsidiary heating of the crucible
is performed from below by the subsidiary heater 9
as the remaining amount of the melt decreases.
This makes it possible to compensate the heat loss
due to the reduction of the area for receiving heat
from the heater 2 irrespective of the remaining
amount of the melt, and the temperature of the melt
can be maintained to be a suitable temperature
without unduly increasing the electric power
supplied to the heater 2. Since it is not required
to markedly increase the electric power supplied to
the heater 2, the temperature distribution of the

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single crystal under pulling is not substantially
influenced. If rather rapid cooling is desired for
the temperature distribution of the single crystal,
the electric power supplied to the subsidiary
heater 9 can be made rather higher, and the
electric power supplied to the heater 2 can be made
rather smaller. Conversely, if rather gradual
cooling is desired for the temperature distribution
of the single crystal, the electric power supplied
to the subsidiary heater 9 can be made rather
smaller, and the electric power supplied to the
heater 2 can be made rather higher. Exemplary
patterns of electric powers supplied to the heater
2 and the subsidiary heater 9 with respect to the
single crystal formation ratio are shown in Fig. 2.

If the method of the present invention is used,
the amount of the melt to be remained in the
crucible can be made small, and therefore a single
crystal can be obtained with a high yield.

In the multi-pulling, after a grown single
crystal ingot is detached from the melt and taken
out from the single crystal pulling apparatus 1,
the raw material is newly added to the raw material
melt remained in the crucible and another single
crystal is pulled again. When the raw material is
additionally introduced, what is important is to
maintain the temperature so that the raw material

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melt should not completely solidify. This is
because, if the raw material melt completely
solidifies in the crucible, a stress is applied to
the crucible by the volume change at the time of
solidification, and the crucible may be cracked.

Therefore, the crucible is subsidiarily heated
from below by the subsidiary heater 9 so that the
melt should not completely solidify after the
detachment of the single crystal ingot. This makes
it possible to compensate the reduction of the area
for receiving heat from the heater 2 irrespective
of the remaining amount of the melt. Further, when
the raw material is additionally introduced, the
temperature of the melt is likely to decrease.
Therefore, the electric power supplied to the
subsidiary heater is increased according to the
introduction of the raw material.

In this way, the temperature of the melt can
be maintained to be a suitable temperature without
unduly increasing the electric power supplied to
the heater 2. As a result, deformation and
degradation of the crucible can be prevented.

Furthermore, if the method of the present
invention is used, the amount of the melt remaining
in the crucible can be made small, and therefore a
single crystal can be obtained with a high yield.

Hereafter, the present invention will be

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explained with reference to the following examples
and comparative examples.

(Example 1)

Silicon single crystals were pulled by using
such a single crystal pulling apparatus 1 as shown
in Fig. 1. The size of the quartz crucible 4 was
32 inches for the inner diameter. The amount of
300 kg of silicon raw material 12 was charged in
the quartz crucible 4, and crystals having a
diameter of 12 inches were pulled. In the range of
the single crystal formation ratio of from 0 to 60%,
the pulling was performed by using only the heater
2. In the range of the single crystal formation
ratio of 60% or higher, subsidiary heating was
performed by the subsidiary heater 9 in addition to
the heating by the heater 2. The electric powers
supplied to the heater 2 and the subsidiary heater
9 were controlled so that the pulling rate for a
portion having a constant diameter of the single
crystals should be maintained to be 0.8 mm/min.
Specifically, at a single crystal formation ratio
of 60% or higher, the electric power supplied to
the heater 2 was maintained to be constant, and the
control of heating concerning the control of the
diameter is attained by the subsidiary heater 9.
In this test, ten crystals were experimentally

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pulled.

(Comparative Example 1)

For comparison, crystals having a diameter of
12 inches were also pulled with the same pulling
apparatus 1, quartz crucible 4 and amount of the
raw material 12 as those of Example 1, but only the
heater 2 was used throughout the experiment. As
for the pulling rate of single crystals, the
electric power supplied to the heater 2 was
controlled so that the pulling rate for a portion
having a constant diameter of the single crystals
should be maintained to be 0.8 mm/min. In this
test, ten crystals were experimentally pulled.

The presence of solidification of the melt was
investigated at single crystal formation ratios of
60%, 70%, 80% and 85%. The investigation results
for Example 1 and Comparative Example 1 are shown
in Table 1 as percentages of the numbers of
crystals for which generation of solidification was
observed relative to the number of experimentally
pulled crystals.

(Table 1)

Single crystal formation ratio (%)	Example 1 (%)	Comparative Example 1 (%)
60	0	0
70	0	20
80	0	50
85	0	100

As shown in Table 1, since heating by the subsidiary heater 9 was added for the period when the single crystal formation ratio was 60% or higher in the single crystal pulling method of Example 1 according to the present invention, single crystals could be stably pulled without causing solidification of the melt for all of the single crystal formation ratios of from 60% to 85%.

On the other hand, in the conventional single crystal pulling method of the comparative example, solidification was occasionally observed at the melt surface at a single crystal formation ratio of 70%. Furthermore, at a single crystal formation ratio of 85%, solidification was generated and the solid matter adhered to the growing interface of the single crystals in all of the pulling tests. Therefore, it became impossible to continue the pulling of the crystals. In Comparative Example 1, since the subsidiary heater 9 was not used, solidification occurred at a single crystal formation ratio of 70%. However, in Example 1,

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since the heating by the subsidiary heater 9 was

performed at a single crystal formation ratio of

60% or higher, solidification was not caused. From

these results, it can be said that the subsidiary

heating by the subsidiary heater 9 was effective

for the period after the single crystal formation

ratio reached and exceeded 60%.

(Example 2)

Crystals having a diameter of 12 inches were

pulled with the same pulling apparatus 1, quartz

crucible 4 and amount of the raw material 12 as

those of Example 1, so that the pulling rate for a

portion having a constant diameter of the single

crystals should be maintained to be 0.8 mm/min.

Prior to the pulling, there were determined, by

calculation based on global heat transfer analysis,

such electric powers supplied to the heater 2 and

the subsidiary heater 9 that the temperature

distribution in the single crystals along the

pulling axis direction should not be changed even

if the single crystal formation ratio increased to

be 60%, 70%, 80% and 85%. When single crystals

were pulled, the electric powers supplied to the

heaters were controlled so as to approach the

calculated electric power values. In this Example,

the electric powers supplied to the heater 2 and

the subsidiary heater 9 were 150 kW and 20 ± 5 kW,
145 kW and 25 ± 7 kW, 140 kW and 28 ± 8 kW, for the
ranges of single crystal formation ratio of 60 to
69%, 70 to 79% and 80 to 85%, respectively. The
reason why electric power supplied to the
subsidiary heater 9 was indicated with a certain
allowance is that it was changed for controlling
the diameter of single crystals.

In order to investigate the crystal defect
density of the pulled single crystals, FPDs (Flow
Pattern Defects) were measured. As for FPD, when a
wafer sliced from a grown silicon single crystal
ingot is subjected to etching with a mixture of
hydrofluoric acid and nitric acid to remove a
surface damaged layer, and surface etching with a
mixture of $K_2Cr_2O_7$, hydrofluoric acid and water
(Secco etching), pits and flow patterns are formed
on the wafer surface. The flow pattern is called
FPD, and it is considered that it consists of voids
formed by aggregation of vacancies.

As a result of investigation of FPD density
distribution of the pulled crystals along the
pulling axis direction, it was demonstrated that
the FPD density fell within a range of 300 to
$320/cm^2$ at any point along the pulling axis
direction, and thus the method of determining the
electric powers supplied to the heaters by

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calculation based on global heat transfer analysis effectively worked.

If the calculation based on global heat transfer analysis is not used, single crystal pulling tests must be performed for a large number of combinations of electric powers supplied to the heater 2 and the subsidiary heater 9 to investigate the crystal defect distribution. Therefore, enormous cost and time are spent for the determination of the single crystal pulling conditions.

However, if the electric powers supplied to the heaters providing uniform defect distribution are preliminarily determined by the calculation based on global heat transfer analysis as in the present invention, the number of pulling tests can be markedly reduced. If the electric power supplied to the heaters are desired to be controlled, the calculation based on global heat transfer analysis can be performed again to reflect a desired degree of gradual cooling of single crystal or desired degree of rapid cooling of single crystal.

(Example 3)

Crystals having a diameter of 12 inches were pulled with the same pulling apparatus 1, quartz

crucible 4 and amount of the raw material 12 as
those of Example 1. Subsidiary heating was
performed by the subsidiary heater 9 for a period
when the single crystal formation ratio was 60% or
higher, and a single crystal ingot was detached
from the melt at a single crystal formation ratio
of 70%. Then, while the electric power supplied to
the heater 2 at the point of the detachment of the
single crystal was maintained and subsidiary
heating was performed by the subsidiary heater 9 so
that the melt should not solidify, additional 110
kg of the raw material was newly introduced into
the remaining melt, and a second single crystal was
pulled at a single crystal formation ratio of 70%.

(Comparative Example 2)

For comparison, pulling was also performed
with the same pulling apparatus 1, quartz crucible
4, raw material 12, single crystal formation ratio
and amount of the additional raw material as those
of Example 3, by using only the heater 2 throughout
the experiment. After the first single crystal was
detached, the electric power supplied to the heater
2 was increased so that the melt in the crucible
should not solidify.

While the quartz crucible was not deformed in

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Example 3, the upper portion of the quartz crucible
body was deformed inwardly in Comparative Example 2.
This shows that the deformation of the crucible can
be prevented by subsidiarily heating the crucible
from below.

The present invention is not limited to the
embodiments described above. The above-described
embodiments are mere examples, and those having the
substantially same structure as that described in
the appended claims and providing the similar
functions and advantages are included in the scope
of the present invention.

For example, the Czochralski method referred
to in the present invention also includes the MCZ
method (magnetic field-applied Czochralski method),
in which a single crystal is grown with applying a
magnetic field to a melt in a crucible. The MCZ
method includes the cusp magnetic field-applied
method, horizontal magnetic field-applied method,
and vertical magnetic field-applied method. The
method for pulling a single crystal according to
the present invention can of course be used also in
the MCZ method, and exert the effect.